Annual Report LWS TR&T Focus Science Topic (FST) team:
Flare Particle Acceleration Near the Sun and Contribution to Large SEP Events

Team Annual Report: July 1, 2008 - June 30, 2009

PI	Investigation title
Ben Chandran, UNH	Stochastic particle acceleration in solar flares
Judy Karpen, GSFC	3D MHD Modeling of Flare Reconnection for Solar Energetic Particle Acceleration
Glenn Mason, JHU/APL (team leader)	Understanding Propagation Characteristics of Heavy Ions to Assess the Contribution of Solar Flares to Large SEP Events
Nariaki Nitta, LMSAL	Solar Flares as a Source of Gradual Solar Energetic Particle Events
Gerry Share, UMd, NRL	Comparison of Accelerated Particle Populations at 1 AU and at the Sun
Allan Tylka, NRL	The Disappearance of Large, Fe-Rich Solar Energetic Particle Events in the Declining Phase of Cycle 23: Implications for the Role of Flares

Second Year Activities:

The FST on Flare particle acceleration near the Sun and contributions to large SEP events had its second meeting January 13-14, 2009, at JHU/Applied Physics Lab. An agenda a list of attendees is below; in addition to all the FST Principal Investigators, several Co Investigators and collaborators also attended. A bibliography of team member activities is below.

The second year activities by team members were as follows:

Ben Chandran (UNH) with Martin Lee and Chung-Sang Ng, and 2 graduate students:

- We developed and tested the WPK code for simulating resonant interactions between waves and particles in flare acceleration regions. We changed the velocity grid to be logarithmic, in preparation for simulations of proton energies to up to approximately 200 MeV. We will be presenting first results from this code in a poster at the Solar Wind 12 meeting in France.
- We carried out analytical calculations of oblique Alfven/ion-cyclotron waves with protons. Most previous analytic calculations have focused on “slab" waves with wave vectors aligned with the background magnetic field. By allowing for other wave

directions, we have significantly extended our analytical understanding of this important type of wave-particle interaction. In particular, these types of waves play an important role in accelerating protons out of the thermal population in stochastic-particle-acceleration models of solar flares.

- We carried out several studies of strong MHD turbulence, focusing on the role of "cross helicity" (an excess of Alfven waves travelling in one direction along the background magnetic field). Our studies have addressed the ways in which cross helicity affects the wave power spectra and the turbulent heating rate.
- We published a paper in Physical Review Letters on the weak turbulence theory of interacting MHD waves, incorporating interactions between all three MHD wave types (Alfven, fast magnetosonic, and slow magnetosonic waves). This theory provides important input into stochastic particle acceleration models, by determining the way in which the fluctuation energy in the system is transferred from large scales to small scales, the distribution of small-scale wave energy in wave-vector direction (anisotropy), as well as the partitioning between different wave modes of the turbulent energy.

Judy Karpen (GSFC) with Spiro Antiochos (GSFC), Rick DeVore (NRL), and Ben Lynch (UC Berkeley SSL):

- We are performing 3D MHD simulations of the flare reconnection in the corona below breakout coronal mass ejections (CMEs). The initial setup is a single bipolar active region imbedded in the global-scale background dipolar field of the Sun, forming a quadrupolar magnetic configuration with a coronal null point. Rotational motions applied to the active-region polarities at the base of the atmosphere introduce shear across the polarity inversion line (PIL). Eventually, the magnetic stress and energy reach the critical threshold for runaway breakout reconnection, at which point the sheared core field erupts outward at high speed. The vertical current sheet formed by the stretching of the departing sheared field suffers reconnection that reforms the initial low-lying arcade across the PIL, i.e., creates the flare loops. Our simulation model, the Adaptively Refined MHD Solver, exploits local grid refinement to resolve the detailed structure and evolution of the highly dynamic current sheet. We are analyzing the numerical experiments to identify and interpret observable signatures of the flare reconnection associated with CMEs, e.g., the flare loops and ribbons, coronal jets and shock waves, and possible origins of solar energetic particles.
- The results of these calculations will be used to determine initial conditions and fluctuation levels for Ben Chandran's particle-acceleration model, as one of our TR&T objectives.

Glenn Mason (APL) with C. M. S. Cohen and R. A. Mewaldt (Caltech), Gang Li (Univ. of Alabama in Huntsville), M. I .Desai (SWRI), D. K. Haggerty (APL), R. A. Leske (Caltech) , and G. Zank and O. Verkhoglyadova (Univ. of Alabama in Huntsville):

- We continued development of the UC Riverside/Univ. Alabama in Huntsville Monte-Carlo solar particle propagation model to examine solar energetic particle (SEP) events

where species with different charge-to-mass ratios (e.g., O vs. Fe) showed similar time-intensity profiles for "shifted" energies. For example, O time intensity profiles in many large events are similar to the Fe profiles when the O profile is taken for ~twice the kinetic energy per nucleon than the Fe. It is possible that this is due the importance of scattering in the SEP event such that the diffusion coefficient rather than particle speed controls the intensity profiles.

- We picked out a single event to fit, settling on the April 15, 2001 event since it showed such energy shifting effects, and the low energy (< 1 MeV/nucleons) particle intensities were not dominated by shock passage as is often the case.
- We then picked particle decay time scales to find a value of the IMF power spectral index that yielded decay times consistent with the observations. Although satisfactory for the decay portion of the event, these fits did not simultaneously fit the rise portion.
- We have found that while it is possible to obtain excellent fits to individual species and energies, it is much more difficult to find a set of interplanetary parameters that fits all the species -- while on the surface this is a discouraging development, it shows that the multiple species measurements provide important and unique constraints on any propagation model fit, and that fits to a single time-intensity profile may not be very significant.
- We are now exploring parameters that affect the rise phase of the particle intensities, with emphasis on the radial dependence of the IMF turbulence. We are in the process of modifying the calculation to include adiabatic deceleration, which is important for the low energies.
- Results of this work have been presented at AGU meetings and in a paper submitted to Astrophysical Journal.

Nariaki Nitta (LMSAL) with Marc DeRosa (LMSAL) and Christina Cohen (Caltech), and collaborators Dave Chenette (LMSAL), Mike Kaiser (GSFC), and Säm Krucker (UC Berkeley SSL).

- We extended the previous work of Nitta, Cliver and Tylka (2003) to more recent and smaller events and also studied radio data. Major findings include
    - the intensity and rise time of protons at >50 MeV depend not only on the CME speed and the location of the source region but also on the direction of the ejection with respect to the nearest open field lines,
    - the type III bursts associated with these high-energy SEP events tend to conform to the characteristics of type III-l bursts as described by Cane et al. (2002) and MacDowall et al. (2003), but the onset time of the type III burst with respect to that of the flare varies from event to event,
    - these SEP events do not appear to be associated with shock signatures as found in some coronagraph images. This work, still in progress, will be written up within a few months.

- A large fraction of Nitta's effort was to co-organize the Coordinated Data Analysis Workshop (CDAW) on Ground Level Enhancement (GLE) events with Dr. Nat Gopalswamy (NASA/GSFC) in January 2009 at the Lockheed Martin Solar and Astrophysics Laboratory in Palo Alto, CA. GLE events are SEP events that reach the neutral atmosphere of Earth. They are rare events and only 16 occurred during solar cycle 23. The meeting was highly relevant to this FST. All of these GLE events had been included in Nitta's LWS TR&T program to analyze intense proton events that extend to >50 MeV. The members of this FST took up about 30% of the ~30 participants of the GLE CDAW. We discussed a wide range of topics from the origins to consequences of the GLE events, planning to publish the efforts during and after the workshop in Space Science Review.

Gerry Share (UMD, NRL), with Ron Murphy (NRL), Jim Ryan (UNH) and Allan Tylka (NRL):

- We are using newly developed nuclear-line templates (Murphy et al. 2009) along with improved detector response functions for *SMM* and *RHESSI* to determine the compositions and spectra of flare-accelerated particles that interact in the solar atmosphere. These can be compared with particle measurements from *ACE*, *IMP-8* and other satellites to determine the relationship between the processes that accelerated flare particles and SEPs. Our preliminary studies suggest that the average flare-accelerated a/p ratio is about a factor of two higher than the photospheric ^{4}He/H ratio and significantly higher than most measurements of this ratio in SEPs and the corona. Using this same technique we have made the first determination of the ambient Ne/O abundance ratio deep in the solar chromosphere. The measured ratio is 0.17±0.04 consistent with coronal observations and not high enough to provide to resolve the discrepancy between new solar abundance models, with lower C, N, O abundances, and helioseismology.
- Analysis of the Ground Level Events on 20 January 2005 and 15 April 2001 continued at the University of New Hampshire. Assuming that the particles arise from a coronal/interplanetary shock and focusing on the leading, anisotropic edge of the event, we find that the spectrum of the 20 January 2005 event is hard at onset and transitions to a softer spectrum in the gradual isotropic phase. The spectra are well fit to power laws in rigidity that roll off exponentially in the region of 1 GV, consistent with shock acceleration within a few solar radii of the flare region. The 15 April event, which is not as intense and has a longer time scale, shows little spectral evolution from the impulsive leading edge spike to the longer duration isotropic phase. These results will be the main findings of the Ph.D. thesis of Mr. Trevor Morgan.

Allan Tylka (NRL) with Ed Cliver (Air Force Research Lab) and William Dietrich (NRL consultant):

- A close connection between non-relativistic (<0.2 MeV) electrons and ^{3}He/^{4}He enhancements at ~1 MeV/nucleon in impulsive SEP events has long been known. However, there have been comparatively few studies of relativistic (>10 MeV) solar electron events and no detailed studies of their ion characteristics. Moses et al. (1989) identified 55 relativistic solar electron events observed by ISEE-3 in 1978-1982. About half of these events showed strong hardening in the rigidity spectrum above a few MV. The origin of this spectral hardening, and how these unusual events fit within our understanding of particle acceleration processes that occur at or near the Sun, has been unclear.
- To investigate what insights these events might hold on the processes by which shocks and flares together contribute to SEPs, we reported for the first time ^{3}He/^{4}He ratios at ~13-24 MeV/nucleon for these events from the University of Chicago's Cosmic Ray Nuclei Experiment (CRNE) on IMP-8.
- We also used CRNE to examine proton fluences and proton/alpha ratios above 10 MeV/nucleon and electron/proton ratios. Large ^{3}He/^{4}He enhancements (exceeding 10%) were preferentially found among events with electron spectral hardening. This and other results favor an important role for stochastic acceleration in the events with electron spectral hardening, although the hardening could also suggest the operation of a second process, such as shock acceleration. The characteristics of the events without electron spectral hardening are consistent with those of shock-accelerated "gradual" SEP events, with a few having more modest ^{3}He/^{4}He enhancements that might be produced by flare remnants in the shock's seed population.

Contributions and collaborations for the FST effort

The primary joint FST effort has been between Judy Karpen, Nariaki Nitta, Ben Chandran's teams where the observational researchers are working to help constrain the parameters space being investigated by Ben Chandran's group. Other efforts are also listed below, but progress is slow since most of the other possible collaborations are awaiting each team's progress on its proposed primary tasks.

1) Characterizing bulk turbulence in flaring regions. Ben Chandran (lead) with Judy Karpen, Nariaki Nitta and their CoIs. The turbulence investigations of Ben Chandran's group cover a very wide range of local conditions, and so would be helped if other models and observations could provide properties of the flaring site. The MHD models used by Judy Karpen's group will be used to calculate bulk properties such as average plasma speeds and various moments in the reconnection region, and also in the regions where shocks form. By this means, the global models will provide a context for the relatively small scale sizes associated

with the turbulence calculations. Observational data on line broadening provided by Nariaki Nitta's group will also help constrain some of the plasma velocities.

2) Comparison of x-ray images from SEP-productive and non-SEP-productive CMEs. Nariaki Nitta (lead) with Allan Tylka and Judy Karpen their CoIs. It has been found that CMEs at moderate speeds of ~1100-1500 km/s are much less productive in making large SEP events during the declining phase of Cycle 23. For selected CMEs in this speed range, they will compare x-ray images to look for possible differences in their topologies that might be related to the SEP productivity.

3) Particle properties of gamma-ray events. Gerry Share (lead) with Allan Tylka, Glenn Mason, Judy Karpen and their CoIs. The FST identified several areas where the gamma-ray data and the derived particle properties at the gamma-ray site can be compared with the interplanetary particle populations. The gamma-ray events are the only events where it can be considered "known" that there were "flare" produced particles, and as such they offer the opportunity to obtain some key insights. The initial and main focus of this group will be to determine particle properties for events that produced gamma ray lines. A secondary focus will be events with gamma rays, but where there were no lines observed over the continuum. A third focus is cases where there were no gamma-rays at the higher energies. In addition, there are several cases where intense gamma ray events did not produce significant interplanetary intensities even though magnetic connection to the gamma rate site was good; these cases will be re-examined to see what limits exist for the particle intensities, and whether, e.g., the loop topologies give any insight into the reason for the apparent lack of escape of the accelerated particles.

4) Shock characteristics at ~2.5 Rs. Allan Tylka (lead) and Judy Karpen and their CoIs. This group will investigate the potential of the Karpen et al. CME model to deliver shock charactersistics in the range of 2-10 solar radii, which might provide useful inputs for SEP acceleration and transport codes.

Next meeting

The next meeting will be held October 25-26, 2009, at the University of New Hampshire.

Presentations

Presentations from the meetings held to date have been put on the Caltech FTP site at: thor.srl.caltech.edu/pub/LWS_Mason/

January 12, 2009

LWS TR&T Focus Science Topic (FST) Team Meeting:

Flare Particle Acceleration Near the Sun and Contribution to Large SEP Events

JHU/ Applied Physics Lab, MP3 Room E183
7707 Montpelier Rd., Laurel, MD 20723

January 13-14, 2009

Daily Schedule:

Tues Jan 13	
9:00 AM	meeting starts
10:30 AM	Break
12:00 noon	Lunch
3:00 PM	Break
5:30 PM	Adjourn
6:00 PM	Group dinner?

Wed Jan 14	
9:00 AM	meeting starts
10:30 AM	Break
12:00 noon	Lunch
1:00 PM	Set date/location for next meeting
3:00 PM	Adjourn

Speakers / topics:

Mason	Welcome, logistics
Kessel (TBC)	HQ message
Progress reports on investigations	
Pongkitiwanichakul	Stochastic particle acceleration in solar flares
Karpen	3D MHD Modeling of Flare Reconnection for Solar Energetic Particle Acceleration
Mason	Understanding Propagation Characteristics of Heavy Ions to Assess the Contribution of Solar Flares to Large SEP Events

Nitta	Solar Flares as a Source of Gradual Solar Energetic Particle Events
Share	Comparison of Accelerated Particle Populations at 1 AU and at the Sun
Tylka	The Disappearance of Large, Fe-Rich Solar Energetic Particle Events in the Declining Phase of Cycle 23: Implications for the Role of Flares

Progress reports on collaborative FST efforts:	
Chandran/ Karpen / Nitta	(with Karpen, Nitta and CoIs): Characterizing bulk turbulence in flaring regions
Nitta	(with Tylka, Karpen and CoIs): Comparison of x-ray images from SEP-productive and non-SEP-productive CMEs
Share	(with Tylka, Mason, Karpen and CoIs): particle properties of gamma-ray events
Tylka	(with Karpen and CoIs): shock characteristics at ~2.5 Rs

Contributed reports (order may change):	
Murphy	New nuclear physics results and implications for SEP acceleration and gamma rays
Share	Application of new physics results to SMM gamma-ray spectrometer
Mewaldt (by phone)	Spacecraft Measurements of The Energy Spectra of Ground Level Events from Solar Cycle 23
Mewaldt (phone)	Properties of Solar Cycle 23 Ground Level Events
deNolfo	COMPTEL/CGRO data analysis plans

Cliver	Electrons as a diagnostic of the contribution of flares to large SEP event
All	Splinter group meetings

Investigator teams:
Chandran, Pongkitiwanichakul
Karpen, CoIs: Antiochos
Mason, CoIs: Cohen, Mewaldt, Li, Desai, Haggerty; Collaborators: Leske, Zank
Nitta, CoI: Cohen
Share, CoIs: Ryan, Murphy; Collaborators: de Nolfo
Tylka, CoIs: Cliver, Dietrich

ATTENDEE LIST as of 1/12/2009

LWS TR&T Focus Team Meeting
Flare Particle Acceleration Near the Sun and Contribution to Large SEP Events
JHU/ Applied Physics Lab, MP3-E183
7707 Montpelier Rd., Laurel, MD 20723
January 13-14, 2009

* = confirmed

Name	Organization	Citizenship
Ramona Kessel	NASA Headquarters, Washington, DC	US
Ben Chandran	Univ. of New Hampshire, Durham, NH	US
* Peera Pongkitiwanichakul	Univ. of New Hampshire, Durham, NH	Thailand
* Judy Karpen	Naval Research Lab., Washington, DC	US
Spiro Antiochos	NASA Goddard Space Flight Center, Greenbelt, MD	US
* Glenn Mason	JHU/Applied Physics Lab., Laurel, MD	US
* Nariaki Nitta	Lockheed-Martin Solar & Astrophys. Lab., Palo Alto, CA	US
* Gerry Share	Naval Research Lab., Washington, DC	US
* Jim Ryan	Univ. of New Hampshire, Durham, NH	US
* Ron Murphy	Naval Research Lab., Washington, DC	US
* Georgia de Nolfo	NASA Goddard Space Flight Center, Greenbelt, MD	US
* Allan Tylka	Naval Research Lab., Washington, DC	US
* Ed Cliver	Air Force Research Lab., Hanscom AFB, MA	US
* Bill Dietrich	Consultant to Naval Research Lab., Washington, DC	US

PUBLICATIONS 2008-2009:

B. Chandran, "Weakly Turbulent Magnetohydrodynamic Waves in Compressible Low-Beta Plasmas," Physical Review Letters, 101, 235004 (2008)

B. Chandran, "Strong Anisotropic MHD Turbulence with Cross Helicity," Astrophysical Journal, 685, 646 (2008)

B. Chandran, E. Quataert, G. Howes, J. Hollweg, and W. Dorland,
"The Turbulent Heating Rate in Strong MHD Turbulence with Nonzero Cross Helicity," Astrophysical Journal,
Accepted

B. Chandran, P. Pongkitiwanichakul, P. Isenberg, M. Lee, S. Markovskii, J. V. Hollweg, B. Vasquez, "Resonant Interactions Between Protons and Oblique Alfven/Ion-Cyclotron Waves in the Solar Corona and Solar Flares," Astrophysical Journal, submitted

Li, G., G. P. Zank, O. Verkhoglyadova, R. A. Mewaldt, C. M. S. Cohen G. M. Mason, and M. I. Desai, "Shock geometry and spectral breaks in large SEP events", *Astrophys. J.,* submitted Dec. 2008.

Murphy, R.J., Kozlovsky, B., Kiener, J., and Share, G. H. "Nuclear Gamma-Ray Deexcitation Lines and Continuum from Accelerated-Particle Interactions in Solar Flares", Accepted for publication in ApJS July 2009.

J. Podesta, B. Chandran, A. Bhattacharjee, D. Roberts, and M. Goldstein, "Scale-Dependent Angle of Alignment Between Velocity and Magnetic Field Fluctuations in Solar Wind Turbulence," Journal of Geophysical Research, 114, A01107 (2009)

INVITED TALKS:

B. Chandran, "Turbulence and the Origin of the Solar Wind," University of California, Berkeley, June, 2008

B. Chandran, "Heat transport and instabilities in galaxy-cluster plasmas," APS Meeting, Dallas, Texas, May, 2009

Verkhoglyadova, O. P., G. Li, G. P. Zank, Q. Hu, C. M. S. Cohen, G. M. Mason, D. K. Haggerty, T. T von Rosenvinge, M. D. Looper, "Proton and heavy ion spectra at 1 AU in the SEP event of December 13, 2006", Voyagers in the Heliosheath, Observations, Models, and Plasma Physics, Kauai, Hawaii, Jan. 9-14, 2009.

CONFERENCE PROCEEDINGS:

W.F. Dietrich, A.J. Tylka, and E.W. Cliver, Proceedings of the 31st International Cosmic Ray Conference (Lodz), in press.

CONTRIBUTED TALKS:

B. Chandran, "Parallel and Perpendicular Energy
Cascades in MHD Turbulence," APS-DPP Minisymposium on the Solar Wind,
Dallas, TX, Nov. 2008

B. Chandran, "Stochastic Particle Acceleration in Solar Flares," Applied Physics Laboratory, Johns Hopkins University, June 2008.

B. Chandran, "Resonant Interactions Between Protons and Oblique Alfven/Ion-Cyclotron Waves in the Solar Corona and Solar Flares," Solar Orbiter Workshop, Sorrento, Italy, 2009.

Desai, M. I., M. A. Dayeh, G. M. Mason, C. M. S. Cohen, R. A. Leske, R. A. Mewaldt, G. Li, "Solar energetic particle acceleration at Coronal Mass Ejection-driven shocks", American Geophysical Union 2008 Fall Meeting, San Francisco, Calif., Dec. 15-19, 2008, EOS Trans. AGU, *89* (53), Fall. Meet. Suppl., Abstract SH22A-05

Desai, M. I., M. A- Dayeh, F. Allegrini, G. Li, G. M. Mason, R. A. Leske, R. A. Mewaldt, and M. A. Popecki, "Solar cycle variations of quiet-time suprathermal and CME-shock accelerated ions", presented at the STEREO-3/SOHO-22 Workshop, Bournemouth, England, April 27 - May 1, 2009.

C. R. DeVore, J. T. Karpen, & S. K. Antiochos, "Simulations of Flare Reconnection in Breakout Coronal Mass Ejections", 2009 meeting of the Solar Physics Division, American Astronomical Society, 14-18 June 2009, Boulder CO.

Li, G., G. M. Mason, R. A. Mewaldt, M. Desai, M. Al-Dayeh, C. M. S. Cohen, R. A. Leske, D. Haggerty, O., Verkhoglyadova, and G. Zank, "Modeling the transport of protons and heavy ions in SEP events", American Geophysical Union 2008 Fall Meeting, San Francisco, Calif., Dec. 15-19, 2008, EOS Trans. AGU, *89* (53), Fall. Meet. Suppl., Abstract SH23C-07

Li, G., G. M. Mason, D. K. Haggerty, R. A. Mewaldt, C. M. S. Cohen, R. A. Leske, M. I. Desai, M. A. Dayeh, G. Zank, and O. Verkhoglyadova, "Heavy ions as probe of solar wind MHD turbulence in SEP events" American Geophys. Union Joint Assembly, Toronto, Canada, May 24-27, 2009, *EOS, Trans. AGU, 90*, Jt. Assem. Suppl., Abstract SH23A-05.

Murphy, R., B. Kozlovsky, J. Kiener, and G. Share, "Nuclear Gamma-Ray Deexcitation Lines and Continuum from Accelerated-Particle Interactions in Solar Flares", D13.0005, April 2009 APS Meeting

Share, G. H., and R. J. Murphy, "Using Gamma-Ray Line Observations to Determine the Chromospheric Neon/Oxygen Abundance Ratio", 40th Solar Physics Division Meeting, Boulder, 2009.

Verkhoglyadova, O. P. , G. Li, G. P. Zank, Q. Hu, C.M.S. Cohen, R. A. Mewaldt, G.M. Mason, D. K. Haggerty, T. T. von Rosenvinge, and M.D. Looper, Modeling of a large SEP event of December 13, 2006 with PATH code", paper EGU2009-2250, presented at European Geosciences Union General Assembly 2009, Vienna, Austria, April 19-24, 2009.

CONFERENCE SESSIONS AND WORKSHOPS ORGANIZED:

Impulsive 3He-rich events, 2008 NSF Shine Workshop, Dolce, UT, June 23-27, 2008; session organized and chaired by D. Haggerty

Coordinated Data Analysis Workshop (CDAW) on Ground Level Enhancement (GLE) events in January 6-9, 2009 at the Lockheed Martin Solar and Astrophysics Laboratory in Palo Alto, CA. workshop organized by N. Nitta with Dr. Nat Gopalswamy (NASA/GSFC)

Impulsive 3He-rich events, 2009 NSF Shine Workshop, Wolfville, Nova Scotia, August 3-7, 2009; session organized and chaired by D. Haggerty